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PREDICTIVE ANALYTICS FOR ROUTE PLANNING, CARGO SCHEDULING, AND INTEGRATED PORT–SHIP LOGISTICS SYSTEMS

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Artificial intelligence-based fleet management has become a central element in large-scale maritime operations. This trend is driven by the growing complexity of global supply chains and the need for more efficient utilization of available resources. The increasing volume of maritime cargo, the intensification of international trade, and the pursuit of reduced operational costs have created a strong demand for technologies capable of enabling continuous monitoring, rapid decision-making, and optimization across every stage of maritime transportation. The use of predictive analytics algorithms offers significant opportunities for accurate route planning, cargo flow control, delay minimization, and effective coordination between port infrastructure and vessel operations.

Integrated logistics systems developed on the basis of intelligent solutions provide a foundation for enhancing the reliability of transportation chains, minimizing human error, and preventing critical disruptions in fleet operations. Real-time consideration of changing climatic conditions, port congestion, economic trends, and geopolitical factors grants shipping companies a competitive advantage and supports the transition to a flexible and cost-effective maritime transport management system.

Many researchers have addressed this issue, offering various strategies and interpretations. For instance, Agrawal et al. (2023) demonstrated how the application of machine learning enabled the prediction of deviations in logistics operations and allowed for timely responses. The implementation of data management systems reduced the risks of delays and disruptions in cargo delivery, while network-based approaches optimized coordination across all segments of the logistics chain.

Specifically in the context of maritime transportation, Chen et al. (2024) focused on the application of machine learning algorithms for route prediction and fuel savings. The use of deep learning to process AIS data improved the accuracy of vessel arrival forecasts, which helped reduce port delays. The integration of such systems with energy management platforms contributed to lower fuel consumption, while autonomous navigation solutions enhanced transport safety. The optimization of tugboat schedules, berth allocations, and container crane operations, taking into account the uncertainty of vessel arrival times, as examined in the study by Chu et al. (2024), demonstrated a substantial improvement in the efficiency of port operations.

The developed algorithms reduced the average vessel idle time, while the use of stochastic planning methods ensured operational stability under unpredictable conditions. The authors also emphasized the importance of integrating such solutions with digital platforms for port resource management, which contributed to a comprehensive improvement of logistics processes.

The challenge of reducing emissions and transitioning to environmentally sustainable transportation was thoroughly addressed in the work of Issa-Zadeh and Garay-Rondero (2025), which analyzed the effectiveness of route optimization systems that consider greenhouse gas levels. The proposed approaches reduced the environmental impact of fleets by 18 to 22 percent. International support for innovation and the expansion of inter-port cooperation were identified as key conditions for achieving global decarbonization goals. The prospects for implementing blockchain technologies in maritime transport were explored in the study by Nguyen et al. (2023). The use of distributed ledger technologies enhanced the transparency of operational processes and reduced delays caused by weather and organizational factors. The integration of blockchain with predictive analytics improved planning accuracy, while the application of smart contracts enabled automated interactions between shipowners and port operators. The resilience of global maritime trade networks was examined in the study by Shen et al. (2025), where network analysis was employed to identify critical nodes in the transport infrastructure whose vulnerabilities could trigger large-scale disruptions. The proposed digital tools supported faster recovery from crisis situations through real-time data exchange between ports, and the development of risk management strategies based on big data ensured continuity in transportation system operations. The experience of decarbonizing coastal shipping was systematized by Vakili et al. (2025), demonstrating that the integration of energy technologies, digital platforms, and regulatory support contributed to a reduction in CO_2 emissions. The study emphasized the need to implement localized solutions in regions with underdeveloped infrastructure and to establish monitoring systems for real-time tracking of environmental indicators. The concept of the "digital twin" proposed by Wang et al. (2024) served as a foundation for managing the safety of port operations. The creation of virtual models enabled the prevention of accidents caused by human error, optimized resource allocation, and improved emergency response efficiency. The integration of these systems with cybersecurity measures ensured their reliability. The analysis of sustainable maritime transport optimization strategies conducted by Xu and Chen (2025) demonstrated significant advantages of using big data analytics, process automation, and the harmonization of international standards. The comprehensive application of these approaches reduced operational costs and enhanced the flexibility of logistics systems, while global data-sharing platforms facilitated coordination among all participants in the transportation market.

The issue of improving the safety and efficiency of maritime routes was addressed in the study by Yim et al. (2025), where the application of AIS data and topographic indicators contributed to the enhancement of navigation systems. Geospatial analysis reduced the risk of accidents, while the combination of topographic models with traffic data enabled accurate predictions of congestion in maritime corridors. The use of visualization technologies improved the quality of decision-making by ship navigators.

Intelligence in fleet management has become particularly important at the current stage of maritime operations due to the significant growth in global trade, the increasing complexity of logistics networks, and the need for the efficient allocation of transportation assets. Maritime logistics is a key component of the global economic system, as approximately 80 percent of all goods worldwide are transported by sea. The expansion of maritime shipping has created a pressing need to improve management processes that ensure navigational safety, timely cargo delivery, and cost optimization. In this context, the integration of artificial intelligence into fleet operations has acquired strategic importance, as traditional management methods are no longer capable of effectively processing massive data volumes and handling the complex interaction scenarios between ports, vessels, and transportation routes. Predictive analytics in maritime operations represents a key area of artificial intelligence application. It utilizes machine learning and deep learning algorithms to process large datasets, including historical routes, meteorological conditions, cargo information, port schedules, vehicle load levels, and other relevant factors. Predictive analytics enables the anticipation of changes in maritime transport, such as weather-related delays, fluctuations in transportation demand, port congestion, and other operational risks. These forecasts support informed managerial decision-making, enhance the flexibility of supply chains, and contribute to cost minimization.

Route planning is one of the central aspects of fleet management. Traditional planning relied on fixed schedules and standard navigation routes, which did not account for variable factors such as weather conditions, the state of port infrastructure, and fluctuating transportation demand. The use of artificial intelligence enables the implementation of adaptive route planning in real time. Route optimization algorithms can analyze alternative paths, assess the risk of delays, consider the economic cost of fuel, and minimize travel time. This is achieved through the use of genetic algorithms, particle swarm optimization, and other combinatorial optimization approaches that allow for the consideration of multidimensional constraints and the identification of the most efficient solutions. Cargo planning represents another critically important area. Maritime transportation involves various cargo types, including containerized, liquid, bulk, hazardous, and refrigerated goods. Effective cargo planning requires the optimization of cargo distribution across the vessel, taking into account weight and volume constraints, storage conditions, safety requirements, and regulatory compliance. Artificial intelligence enables automated classification and load forecasting, determination of optimal cargo combinations, and planning of container distribution based on routes and port operations. Machine learning allows for the prediction of cargo handling time at ports, assessment of delay risks, and efficient utilization of the vessel fleet. Integrated port and vessel logistics systems represent the next level of complexity in fleet management. Modern ports function as complex hubs where loading and unloading, transshipment, customs procedures, and internal logistics occur simultaneously. The integration of port and vessel systems using artificial intelligence allows for the synchronization of operations, forecasting of berth workloads, optimization of vessel queues, and planning of crane and transport resource allocation.

These systems are capable of processing vast amounts of data in real time, which enables prompt responses to changes in vessel schedules, cargo delivery delays, or weather conditions. This contributes to increased port throughput and reduced vessel idle time, which, in turn, lowers operational costs. Predictive analytics also encompasses the assessment of maritime transport risks. Such risks may be associated with weather conditions, technical malfunctions of vessels, security breaches, port congestion, or even geopolitical events. The use of artificial intelligence makes it possible to develop early warning systems that, based on historical data and forecasting models, predict the likelihood of specific events and recommend mitigation measures. This involves the application of regression models, neural networks, time series analysis, and scenario modeling. The results of such analytics support decision-making related to route adjustments, schedule changes, or cargo reallocation.

One of the promising directions in maritime logistics is the integration of autonomous vessels into fleet operations. Autonomous ships are capable of completing voyages without constant onboard crew presence by utilizing navigation systems, sensors, machine learning algorithms, and communication with shore-based control centers. The application of artificial intelligence for managing autonomous vessels enables route optimization, speed and fuel consumption control, collision avoidance, and adaptation to changing environmental conditions. The integration of autonomous ships into the broader fleet requires the development of complex management systems that ensure coordination between conventional and autonomous vessels, delay forecasting, and efficient cargo flow planning. A significant component of these integrated systems is the use of big data and real-time analytics.

The vast amount of information on maritime routes, ports, vessels, cargo, weather conditions, and economic factors creates a complex environment for effective management. Artificial intelligence enables the structuring of this data, the identification of key performance indicators, forecasting, and the generation of optimal solutions. The use of Internet of Things (IoT) technologies ensures data collection from vessel sensors and port equipment, allowing access to up-to-date information on cargo conditions, vessel locations, and port congestion. A key aspect is the development of digital twins for maritime operations. These models are accurate virtual replicas of ships, ports, or entire logistics chains, which makes it possible to run simulations, test scenarios, and forecast the outcomes of management decisions without risking real-world operations. Artificial intelligence is used to analyze simulations, optimize routes, forecast cargo volumes, and identify potential bottlenecks in logistics processes. This significantly enhances planning accuracy and reduces uncertainty in maritime transport.

A key area of development is the advancement of artificial intelligence to support strategic fleet management. Predictive analytics systems make it possible to model the evolution of maritime logistics networks, assess the potential for port expansion, plan investments in transport capacities, and make informed decisions regarding fleet development based on future demand. This enables effective resource management at the macro level, enhances the competitiveness of transport companies, and contributes to the stability of the global logistics system.

In maritime management, the integration of artificial intelligence with other technologies, such as the Internet of Things, big data, digital twins, and autonomous systems, is shaping a new management paradigm. This shift allows for a transition from reactive to preventive approaches, in which decisions are based on forecasts and simulations rather than solely on past experience. Such a transformation creates the foundation for sustainable development in maritime logistics, improves the safety and efficiency of transportation, and provides competitive advantages to companies that actively adopt innovative solutions.

Conclusions. The integration of artificial intelligence into large-scale maritime operations significantly enhances the efficiency, safety, and adaptability of logistics processes. Predictive analytics enables the optimization of shipping routes, cargo planning, and resource allocation in ports, reducing delivery times and fuel consumption while minimizing the likelihood of delays and accidents. The integration of port and vessel systems based on AI supports centralized, real-time coordination of operations, which increases the throughput and adaptability of logistics networks. The use of autonomous vessels, digital twins, and machine learning algorithms facilitates strategic planning and forecasting of fleet development, ensuring the stability and competitiveness of maritime transportation in the context of the global economy.

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